The Takanodai landslide, Kumamoto, Japan: insights from post-earthquake field observations, laboratory tests and numerical analyses

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BACKGROUND

On 14-16 April 2016, a series of earthquakes of Mw 6.2-7.0 struck the Island of Kyushu, Japan. Among many landslides, the earthquakes caused the failure of a gentle slope near the Aso Volcanological Laboratory in Minamiaso Village. This large-scale runout slope failure, known as the Takanodai landslide (Figure 1) destroyed at least 7 houses and killed 5 people, threatened many other houses and blocked several roads.

Between April and October 2016, as a part of the NZSEE LFE Kumamoto Mission and J-Rapid Kumamoto Project, the Authors conducted a series of geotechnical damage surveys and field investigations in the Mount Aso Caldera, and retrieved samples of volcanic soils at the Takanodai site to be characterized in the laboratory. The primary objective of this research effort was to provide in-depth understandings into the failure mechanism of the Takanodai landslide and evaluate the liquefaction potential of the Aso pumice believed to be the key soil responsible for the activation of the landslide.

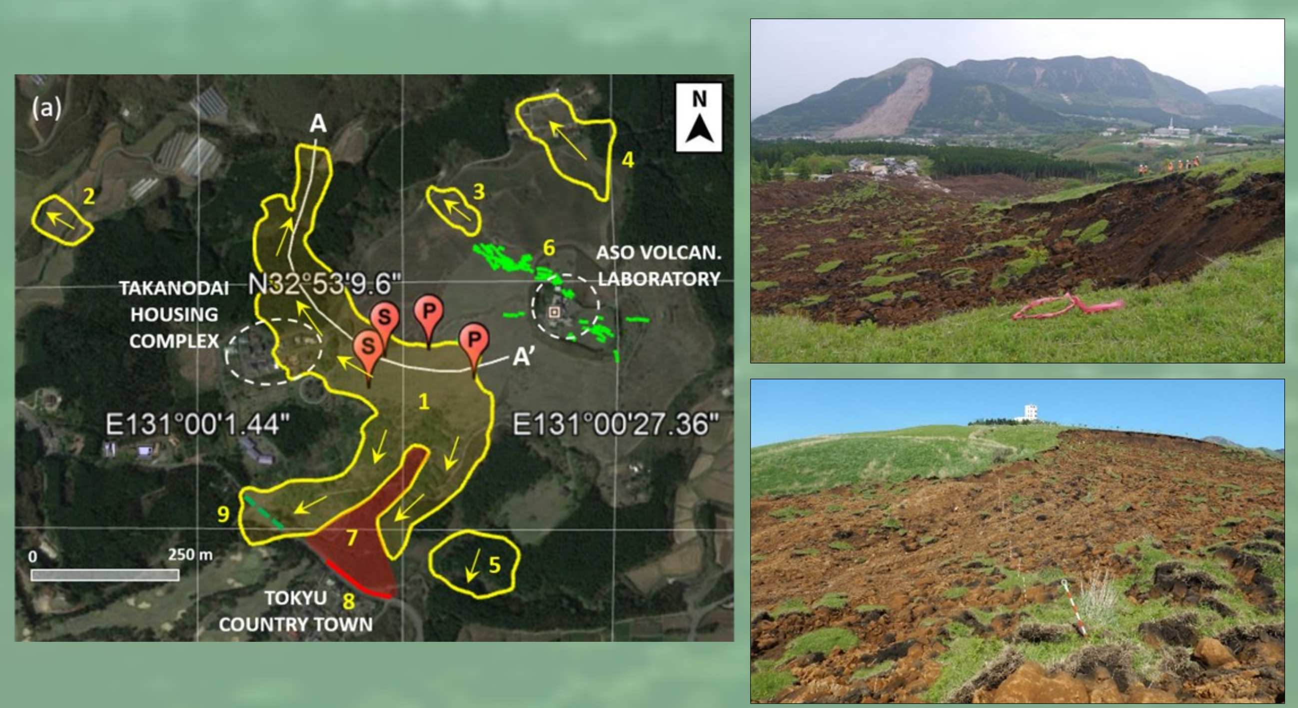


Figure 1. Takanodai landslide (Chiaro et al., 2017)

KEY OBJECTIVES

- Examine and provide insight into the failure mechanism of the Takanodai landslide using numerical geotechnical models
- Evaluate the liquefaction potential for the Aso pumice soil responsible for the initiation of the landslide

METHODOLOGY

A series of monotonic and cyclic undrained torsional simple shear tests were carried out on reconstituted specimens of the Aso pumice.

Numerical investigations including dynamic soil response and seismic slope stability analysis were performed by using the Quake/W and Slope/W software.

SOIL PARAMETERS

Table 1. Summary of soil parameters used in the analysis

Material	Unit Weight (kN/m^3)	Poisson's Ratio	G_{max} (MPa)	Strength parameters c' (kPa)	Strength parameters ø' (°)
Kuroboku	11.18	0.25	27	15.3	23.7
Volcanic Ash (1)	12.85	0.25	27	15.3	23.7
Volcanic Ash (2)	19.23	0.25	35	15.3	23.7
Aso Pumice	11.34	0.25	50	0	40
Stiff Clay	19.23	0.25	100	150	23.7
Bedrock	22	0.25	450	-	-

INPUT GROUND MOTIONS

Earthquake records obtained from KMM007 Station were applied at the base of the slope model for this analysis. The earthquakes considered were the 14 April (M_w 6.2) and 16 April (M_w 7.0) events.

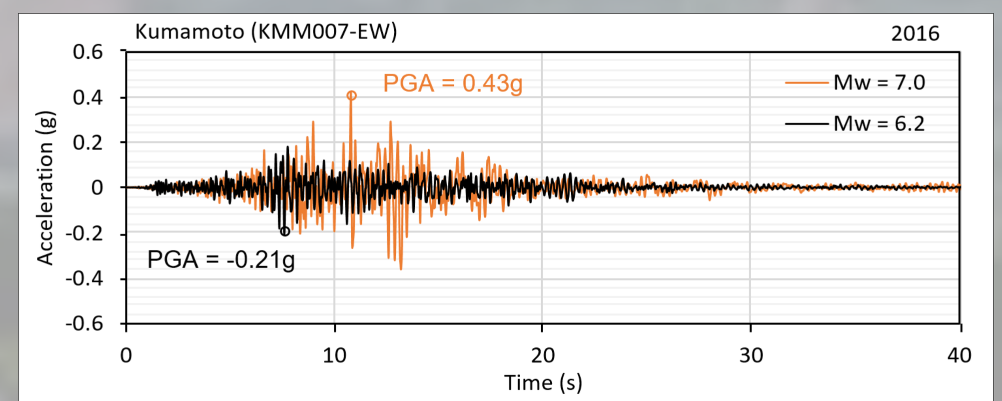
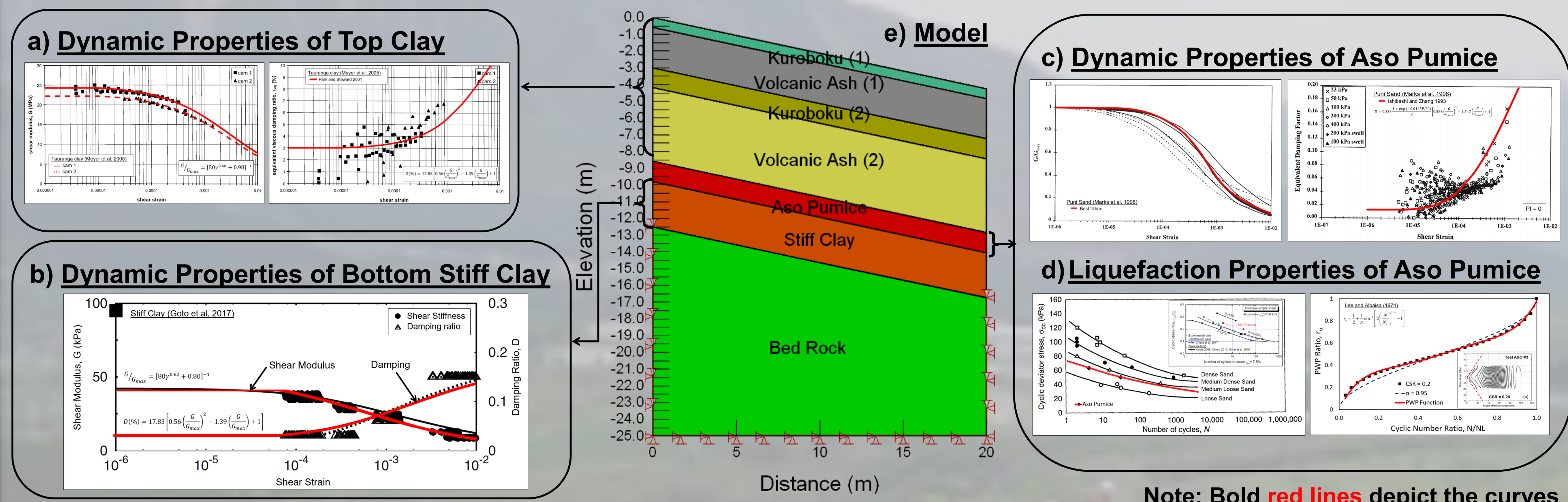


Figure 2. 2016 Kumamoto earthquake ground motions

MODEL GEOMETRY AND SOIL PROPERTIES

In Quake/w, strain-dependant shear modulus and damping values were required for each soil element in order to conduct a dynamic analysis using the equivalent linear method. These properties are summarised in Figure 3. The sand-like behaviour of Aso pumice resulted in susceptibility to liquefaction when subjected to earthquake shaking. Liquefaction characteristics and generation of excess pore water pressures in the pumice were modelled using pore water pressure and cyclic number functions derived from Umar et al. (2017).



Note: Bold red lines depict the curves used in this study.

Figure 3. Soil profile and its associated dynamic characteristics

NUMERICAL SIMULATION RESULTS

Step 1: A slope segment was created as seen in Figure 3(e) to verify the model accuracy and check the sensitivity of soil parameters (Table 1) and the pumice layer thickness. Preliminary results indicated the onset of liquefaction in the pumice layers in addition to significant deformation under intense shaking could be the cause of the slope failure. Analyses were then carried out on the entire slope profile.

Step 2: The foreshock ground motion recorded at the KMM007 station was used in the analysis. It was observed that the Takanodai slope failure was not activated, matching eye-witness accounts of a non-failure before the mainshock. The dynamic factor of safety was FS>1 (Figure 4).

Step 3: The mainshock ground motion recorded at the KMM007 station was used. During this event, slope failure was predicted as the FS against slope failure dropped to 0.794 (Figure 4).

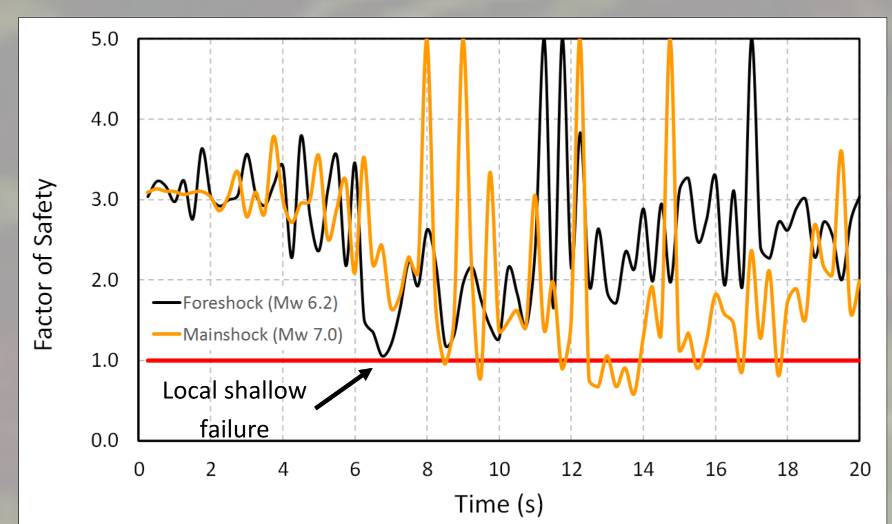


Figure 4. Dynamic factor of safeties during the Kumamoto earthquake

Moreover, the failure surface displayed from the Slope/w analysis (Figure 5) was found to be in agreement with that observed at the site (Figure 6).

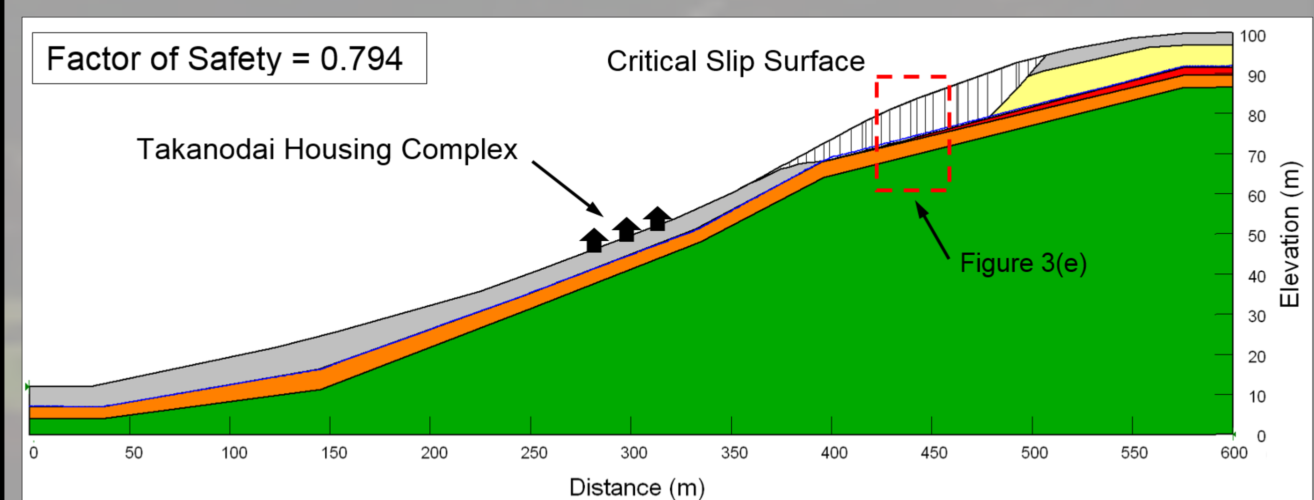


Figure 5. Slope/w model showing critical slip surface

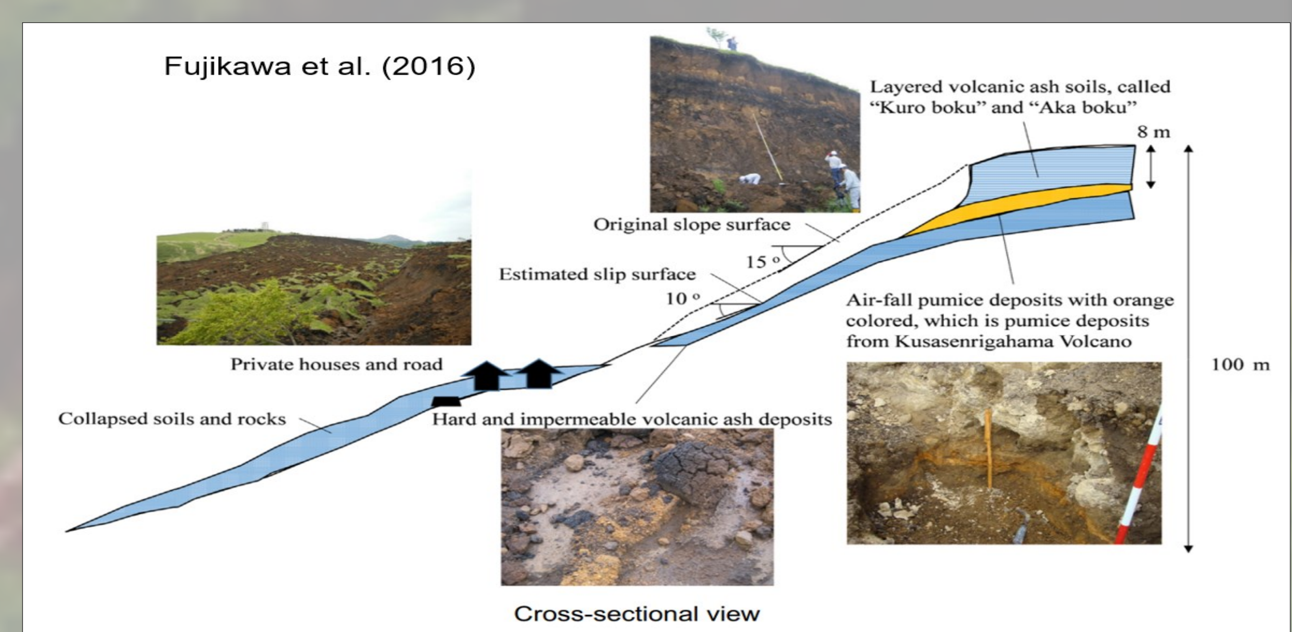


Figure 6. Landslide failure mechanism identified at the site (Mukunoki et al.,2016)

CONCLUSIONS

- This was only a preliminary investigation of the Takanodai landslide. However, it was confirmed that the soil responsible for the landslide triggering was the pumice layer.
- The implemented numerical dynamic model was able to capture the slope stability and failure features of a complex soil profile under seismic events. This tool can be useful to conduct parametric studies with the ultimate goal of refining landslide hazard maps.

FUTURE RESEARCH

- A more robust effective stress analysis is being carried out to provide in-depth insights into this slope failure.
- Possible effects of site amplification and distance attenuation between the KMM007 station and the landslide area are being investigated.

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